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Pulse Height Spectrum Measurement Experiment for Code Benchmarking: First Results

K.E. Sale, J.M Hall and C.M. Brown

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Pulse Height Spectrum Measurement Experiment for Code Benchmarking: First Results*

K.E. Sale, J.M. Hall and C.M. Brown

Lawrence Livermore National Laboratory

Abstract. We have completed a set of gamma-ray pulse height benchmark experiments using a high purity germanium detector to measure absolute counting rate spectra from ^{60}Co, ^{137}Cs and ^{57}Co isotopic sources. The detector was carefully shielded and collimated so that the geometry of the system was completely known. The measured absolute pulse height spectrum counting rates as a function of detector position relative to the source are compared to energy deposit spectra calculated using the Monte Carlo radiation transport code COG[1]. We present here a small subset of our results. The agreement between the calculated and measured spectra and known sources of discrepancies will be discussed

INTRODUCTION

Monte Carlo radiation transport codes are in wide use in research and industry throughout the world. Although the codes have been well tested in some specific applications the tests have generally been against integral data, e.g. dose, total energy deposit or activation. In this paper we present the first results for a photon transport benchmark experiment testing the capability to predict absolute differential results, specifically pulse height counting rate spectra in a high purity germanium detector. There is no scaling employed to help the predictions match the experimental data.

THE EXPERIMENT

In our design of the experiment we wanted to have a geometry that was simple enough that it could be sufficiently accurately and completely modeled. The main tactics we employed were to minimize the mass of supporting structures and carefully collimate the detector and source. A second goal was to provide data that would test the quality of code predictions over a wide range of materials (range of atomic number) and a wide range of penetration depth. The materials around the source ranged from carbon (Z=6) to tungsten (Z=74). Material thickness ranged from essentially zero to over 500 mean free paths through the thickest part of the source collimator. The third goal was to perform a test with no "adjustments" or normalization factors. To this end we used sources with known, NIST traceable strengths. A photograph of the experimental set-up is shown in Figure 1. Four different collimators for the source were used made of graphite, aluminum, iron and Heavimet (a tungsten alloy). The source holder and collimator could be rotated keeping the source position fixed. Pulse height spectrum counting rates were measured using ^{60}Co, ^{137}Cs and ^{57}Co isotopic gamma-ray sources in each of the collimators at collimator rotation angles of 0°, 15°, 35°, and 90° (all together 48 histograms plus several background measurements).

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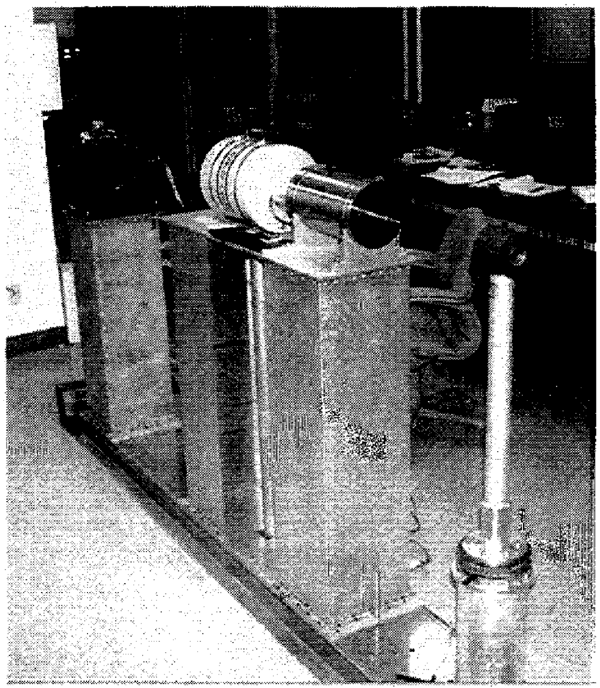

FIGURE 1. Photograph of the experiment apparatus. From upper left to right the alignment scope, detector dewar, steel detector collimator, graphite source collimator and plastic source holder are visible. Each piece is mounted on a low mass support.

At 0° most of the flux was unscattered with a contribution from small angle scattering from the walls of the collimators. This case tested the quality of the physics simulation within the bulk of the germanium detector. At 15° the source was just obscured from the detector position, part of the inside of the throat of the collimator was still visible. This arrangement was meant to be sensitive to small angle scattering. The 35° setting was chosen to maximize the amount of material between the source and the detector, testing accuracy of the predictions for deep penetration. At 90° the flux at the detector was a mixture of direct and highly scattered photons.

Data acquisition was done using a standard system (Canberra InSpector Multi-Channel Analyzer run with Canberra's Genie-2000 software) into 4096 channels. We used the same system gain for the ^{60}Co (E_γ= 1.1732, 1.3325 MeV) and ^{137}Cs (E_γ= 0.66166 MeV) sources and a higher gain for the ^{57}Co (E_γ= 0.12206, 0.13627 MeV) source. We also measured background spectra with each source collimator at each system gain. These spectra were scaled to the same live time as the source spectra and subtracted from the measured data to produce the spectra with which the predictions were compared.

THE PREDICTIONS

The pulse height spectrum predictions were made using the Monte Carlo radiation transport code COG[1]. The model for the germanium detector used as-built dimensions for the specific detector we used (a 70% relative efficiency high purity Ge detector from Ortec). It has been our experience that it is nearly impossible to over emphasize the importance of using a sufficiently accurate and complete geometric model to achieving correct results. COG generated pictures of the geometry model are shown in Figure 2.

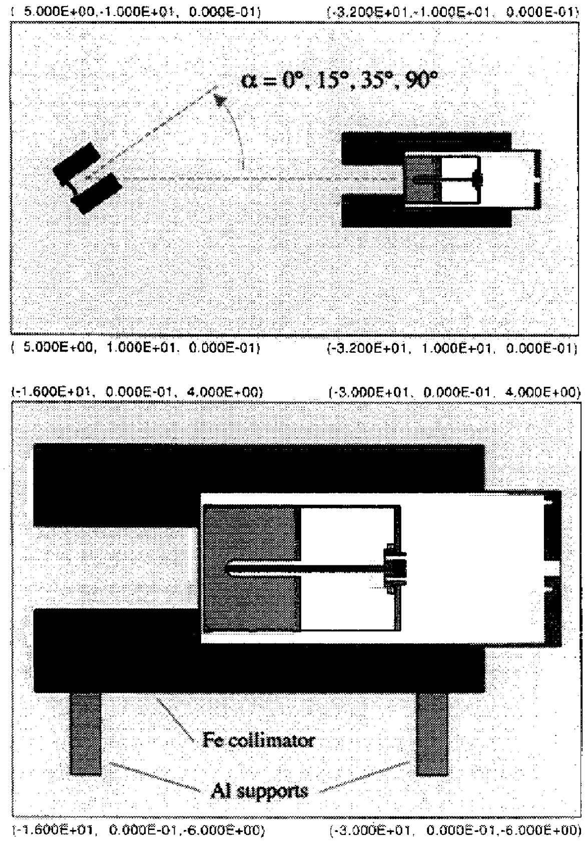

FIGURE 2. COG generated cross sectional pictures of the geometry model. The upper picture shows the source holder and collimator, the detector collimator and detector. The lower picture is of the detector, its collimator and support.

In our simulations we used the NIST traceable source strengths from the manufacturer of the sources and the known source ages to make an absolute prediction of the energy deposit spectrum counting rates (counts per second per MeV of energy deposited). There is no scaling factor needed in order to compare the predictions to the measured data.

The detector in this experiment was well collimated so that secondary electrons generated in the detector were unlikely to escape, therefor in this problem, tracking of charged particles was unnecessary. Any charged particles generated were treated with the zero-range approximation and the energy they would have carried deposited at the interaction site. The photons were tracked using the EPDL data base.

The Monte Carlo predictions were performed as follows. For each source an energy grid was chosen with very narrow bins around the photopeaks and other expected features in the spectrum and much wider bins over the rest of the spectrum, which was expected to be quite featureless. In this way good statistical convergence can be achieved everywhere along with good energy resolution where it is needed.

The final step in producing the predicted pulse height spectra was to convolve the energy deposit histograms with a detector response function. We chose to use a Gaussian peak shape with an energy dependant width which was inferred from the observed widths of about a dozen peaks in the background spectra we measured. The fact that the calculational energy grid was different from the measurement grid and non-uniform makes the convolution with the experimental (electronic) peak shape slightly more complicated.

THE RESULTS

Due to the space constraint for this paper we have chosen to show only our data and predictions for the ^{60}Co spectrum with a iron source collimator rotated to 15° and a ^{57}Co spectrum in the aluminum collimator at the same position. These two cases are neither the easiest nor the most difficult to predict. In these cases the agreement between the convolved COG prediction and the experimental data is excellent as seen in Figure 3. The overall agreement between experiment and perdiction is excellent. There is a systematic discrepancy, possibly due to an inaccurate source strength, between the ^{137}Cs measurements and predictions. Also the count rates were so low for the ^{57}Co source in the higher Z collimators that backgounds dominated the experimental data making it difficult to assess the quality of the predictions.

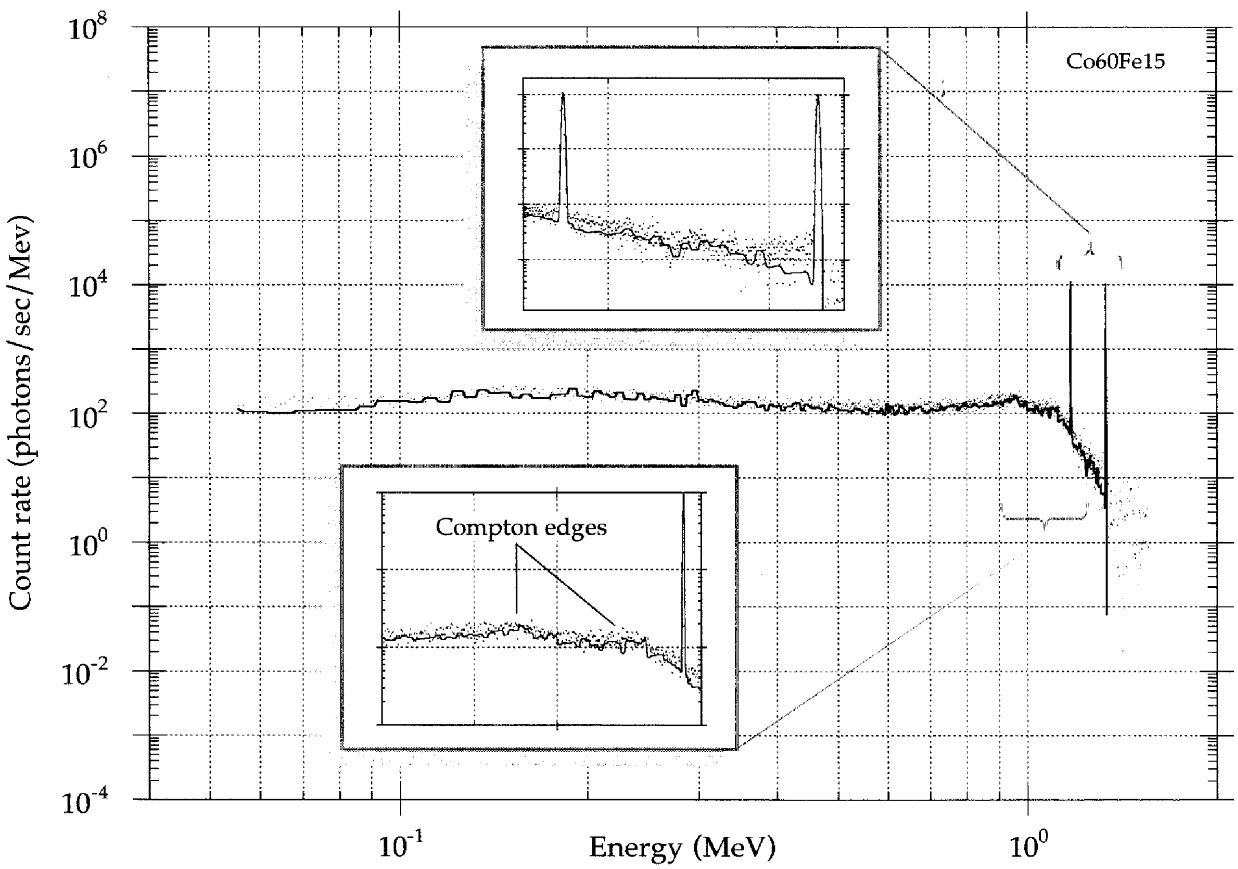

Figure 3a ^{60}Co in the iron collimator at 15°.

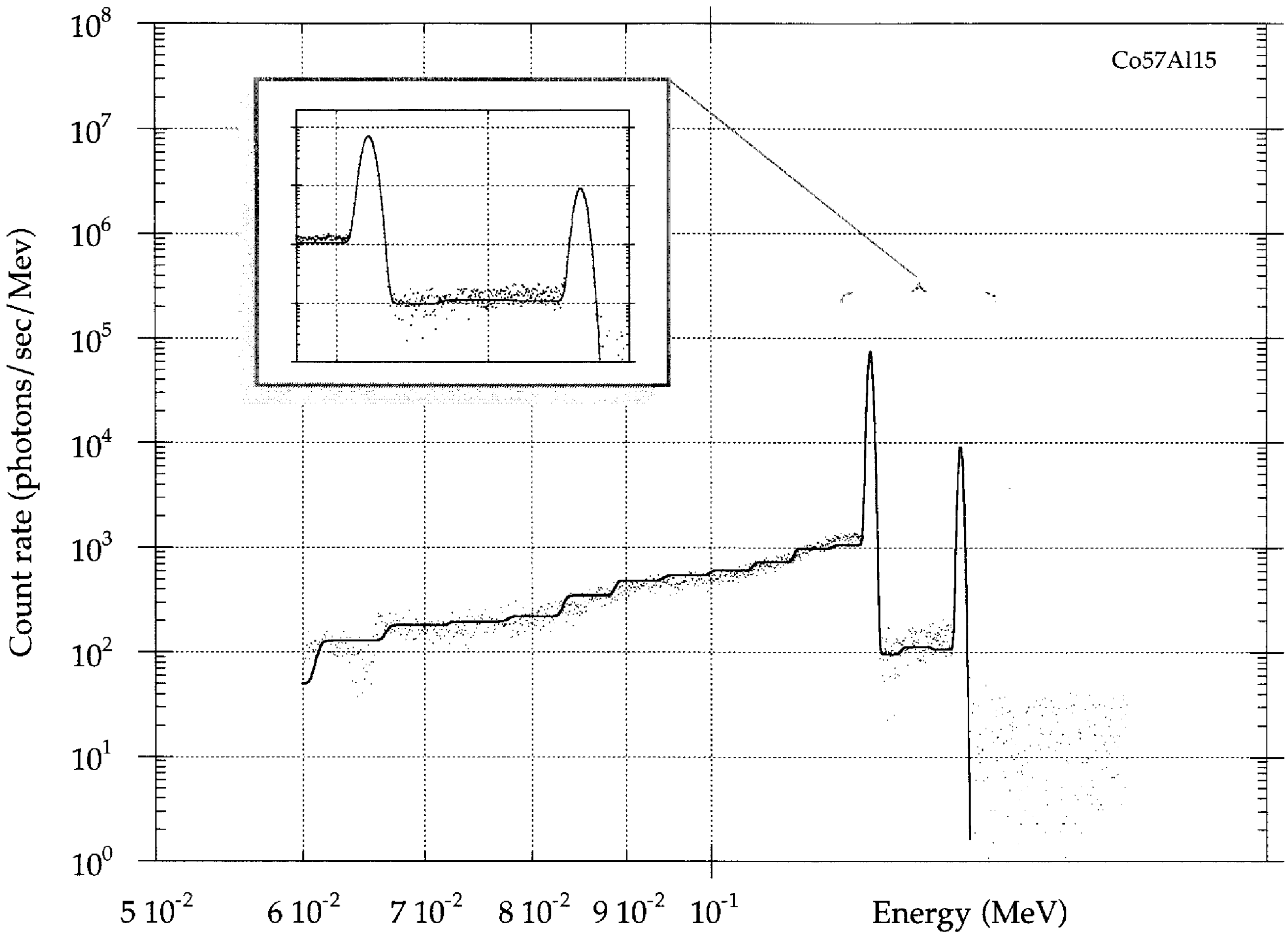

Figure 3b ^{57}Co in the aluminum collimator at 15°.

FIGURE 3. Measurements and predictions of pulse height histograms for ^{60}Co in the iron source collimator at 15° (upper plot) and ^{57}Co in the aluminum source collimator at 15° with particular features highlighted in the insets.

REFERENCES

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University of California
Lawrence Livermore National Laboratory
Technical Information Department
Livermore, CA 94551